AEM
Association of Equipment Manufacturers

Non-Road Automation & Autonomy Terminology Alignment Framework



Connecting Established Terminology, Areas Of Conflict, and Future Definition Needs

AEM FUTURES COUNCIL

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Introduction to Automation and Autonomy

Automation and autonomy describe related, but distinct, ways that machines and systems take on work. In a general sense, automation allows a system to execute pre-defined functions, sequences, or control actions according to programmed rules. The human remains responsible for the broader operation, even when individual functions are performed automatically. Autonomy goes further by adding the ability to perceive relevant conditions, make decisions, and act toward an assigned objective within defined operating conditions and boundaries with less continuous human control. Neither concept is all-or-nothing. A machine may combine manual, assisted, automated, and autonomous capabilities depending on the task, environment, and operating mode.

In agriculture, the distinction can be seen in the progression from guidance, section control, variable-rate application, and automated implement functions toward machines that navigate, detect obstacles, adjust to field conditions, and complete defined field operations under active or passive supervision. Agriculture also demonstrates why autonomy must be understood in context. Weather, terrain, crop variability, animals, field boundaries, road travel, refueling, resupply, and mixed fleets mean that a machine may operate at different levels during different parts of the same workday.

In construction, automation appears in capabilities such as machine guidance, grade control, operator-assist functions, collision warning, and repeatable control of specific machine movements. Autonomy becomes more practical when a task is repetitive, the workzone is defined, and operating conditions can be bounded, such as soil compaction, rolling, selected grading, material movement, commercial mowing, or work on controlled sites. Dynamic jobsites with changing terrain, temporary hazards, multiple trades, people on foot, attachments, and evolving work plans will continue to depend on human judgment and oversight even as machine responsibility increases.

This paper is designed as an alignment framework rather than a universal dictionary. It helps readers distinguish between terminology that already has harmonized meaning, terminology that changes meaning by sector or source, and emerging non-road concepts that still require additional industry discussion. That distinction is important for education and communication today and for the development of credible adoption, utilization, readiness, and safety benchmarks in the future.

Established Industry Foundations for Terminology

The conversation around automation and autonomy is supported by decades of work across agriculture, construction, mining, robotics, and adjacent industries. Manufacturers, standards development organizations, researchers, safety experts, and other stakeholders have collaborated to establish terminology, operating concepts, safety principles, and functional classifications that provide a common foundation for discussing increasingly automated and autonomous systems.

These efforts have resulted in international standards, technical reports, industry guidance documents, safety frameworks, and assessment methodologies that define concepts such as machine guidance, remote operation, autonomous functions, collision avoidance, operational domains, human oversight, and autonomy assessment.

For readers interested in how these definitions are developed and maintained, AEM's Standards Development - Autonomy whitepaper provides an overview of the consensus-based standards development process and highlights the collaborative efforts underway to establish terminology, safety expectations, and technical requirements for autonomous agricultural equipment. The paper also illustrates the important role that industry standards play in supporting innovation, interoperability, safety, and market adoption.

Areas Where Industry Has Already Defined Terms

Agricultural Automation and Autonomous Functions

Agricultural machinery has established terminology and safety concepts through standards such as ISO 18497, which addresses automated and autonomous agricultural machine functions. These efforts distinguish among partially automated, semi-autonomous, and autonomous functions while providing guidance for machine design, safety considerations, and information for use. The agricultural sector's work reflects the unique operating environment of farms, including variable terrain, changing weather, biological systems, and mixed fleets of equipment.

Earthmoving, Construction, and Mining Autonomy

Construction, earthmoving, and mining equipment sectors have developed terminology addressing autonomous machines, autonomous operating modes, remote operator control, levels of automation and autonomy, and machine operating domains. Standards such as ISO 17757, ISO 15817, and ISO 7334 provide vocabulary and concepts specific to non-road equipment operating in worksites, mines, and controlled environments. These efforts help define how responsibility is shared between operators and machines and how increasingly automated systems should be described.

Safety, Risk Reduction, and Assurance

Industry has also established terminology surrounding collision warning systems, collision avoidance systems, safety cases, risk reduction, and machine safeguarding. Standards such as the ISO 21815 series and assurance frameworks such as UL 4600 provide language and methodologies that support discussions around acceptable risk, safe system behavior, and evidence-based safety arguments for autonomous systems.

Robotics and Autonomy Assessment

Not all terminology development has focused on machine classifications or operating modes. Organizations such as the National Institute of Standards and Technology (NIST) have contributed frameworks for evaluating autonomy itself. The ALFUS framework introduced concepts such as human independence, mission complexity, and environmental complexity, helping industry understand that autonomy cannot always be described through a single linear scale.

Terms With Multiple Definitions or Context-Specific Meanings

Some of the most consequential terminology challenges are not caused by missing definitions. They arise because different sectors use the same word in different ways. On-road frameworks emphasize the dynamic driving task and fallback. Earth-moving standards focus on automated operating systems, operator roles, operational domains, and fallback. Agricultural machinery standards organize partially automated, semi-autonomous, and autonomous functions around machine design and safety. Unmanned-system frameworks may evaluate autonomy through human independence, mission complexity, and environmental complexity.

For someone trying to understand the non-road space, these differences can make apparently simple questions difficult. A customer may hear "autonomous" and assume there is no operator, while a manufacturer may mean a bounded function under supervision. "Remote operation" may mean direct teleoperation in one context and higher-level oversight in another. "Workzone" can refer to a construction planning area, a robot operating area, or the boundary associated with an autonomous task. These are not merely editorial differences. They affect product claims, training, safety expectations, incident reporting, policymaker understanding, and the ability to compare adoption or performance.

Core Concepts

These terms shape how stakeholders understand the overall capability of a machine or system:

Term	Intent within non-road applications	How the term varies
Automation	State the function being automated, the human responsibility, and whether functions operate independently or as a system.	May describe one pre-defined function, several integrated functions, or a broader workflow depending on the source and sector.
Autonomy	Describe the assigned task, operating conditions, boundary, supervision model, and machine decision authority.	May be expressed as a level, a degree of human independence, or a system capability bounded by mission and environment.
Autonomous system	Define the system boundary before discussing capability, responsibility, safety, or performance.	May describe a machine, a machine-plus-implement, a fleet, or a wider system of machines, software, and services.
Autonomous operation	Identify whether the operation is supervised, unsupervised, task-limited, or conditionally available.	May imply passive supervision, no real-time supervision, or simply operation of an autonomous function.

Human Responsibility Concepts

These terms determine who is expected to observe, decide, intervene, and remain accountable during operation:

Term	Intent within non-road applications	How the term varies
Operator	Use role-specific terms and identify whether the person controls, supervises, dispatches, or maintains the system.	May refer to an on-board driver, remote controller, task initiator, supervisor, or person responsible for a fleet.
Supervision	Distinguish active from passive supervision and state intervention expectations and response constraints.	Can mean continuous active monitoring, passive monitoring, exception response, or organizational oversight.
Supervised autonomy	Specify scope of awareness, number of machines, intervention triggers, and whether supervision can be found on-site or remote.	Often used for systems that operate independently while a human monitors and can intervene, but the required attention and intervention model vary.
Remote operation	Reserve the term for direct control and separately define remote supervision and remote assistance.	May describe direct human control, teleoperation, or remote intervention in an otherwise autonomous task.
Remote supervision	Define monitoring expectation, intervention authority, connectivity assumptions, and system response if supervision is unavailable.	May range from continuous monitoring to exception-based oversight.

Operational and System Concepts

These terms describe where work happens, how tasks are bounded, and what kind of machine or system is being discussed.

Term	Intent within non-road applications	How the term varies
Operational domain	Use a non-road description that includes task, terrain, weather, access, people, machines, connectivity, and boundary conditions.	May refer to an on-road operational design domain, an earth-moving operational domain, or a broader set of environmental and task conditions.
Autonomous task	Define the start and end state, objective, machine responsibility, human role, and completion criteria.	May refer to a single function, mission, work plan, or complete job.
Workzone	Differentiate the overall workzone from the machine operating boundary and exclusion areas.	May denote a project area, robot work area, geofenced operating area, or broader site plan.
Geofence	Define boundary source, accuracy, enforcement behavior, exclusions, and failure response.	Usually means a virtual boundary, but requirements for precision, enforcement, vertical extent, and response to breach vary.
Mobile robot	Use only when the machine and environment match the source scope; otherwise use non-road machine terminology.	May be used broadly in robotics or narrowly for an industrial mobile robot operating in a controlled workplace.
Autonomous mobile robot	Describe navigation, task capability, supervision, and environment rather than using the label alone.	Common in industrial settings, but may be applied informally to off-road machines that have different tasks, environments, and safety assumptions.
Industrial mobile robot	Retain as a reference term, not a default label for non-road equipment.	A defined industrial context may include structured or semi-structured workplaces with trained personnel, unlike many farms and jobsites.

Terms Requiring Future Industry Definition

Automation and autonomy are moving beyond isolated machine functions toward supervised operations, connected implements, coordinated fleets, and workflow-level execution. Several concepts used by technology developers and adjacent industries do not yet have a sufficiently clear, recognized, and directly applicable non-road definition. This section provides a glimpse into where the industry is today. The descriptions below are intended to illustrate the scope and meaning that these terms are often intended to

convey in non-road automation and autonomy discussions. They are provided to help frame future industry dialogue and should not be interpreted as standards, conformity criteria, or final AEM positions.

The value of proposing working language now is practical. It exposes where assumptions differ, gives members something concrete to test against real agriculture and construction use cases, and creates a starting point for future guidance or standards work. It also prepares the ground for benchmarking.

Readiness, interoperability, supervision, utilization, and safety cannot be measured consistently until the industry defines the unit, boundary, role, and outcome behind each metric.

Human-Machine Interaction

These concepts clarify how people remain involved as machines assume more responsibility:

Term	Intended scope	Why it matters now
Human-in-the-loop	An operating arrangement in which a human must approve, initiate, or complete a decision or action before the system proceeds.	Clarifies where human authorization is required and prevents assisted decision-making from being described as independent autonomy.
Human-on-the-loop	An operating arrangement in which the system acts independently by default while a human supervises and can intervene.	Provides a practical description of supervisory operation expected in many near-term non-road deployments.
Human-out-of-the-loop	An operating arrangement in which the system completes the assigned task without real-time human supervision.	Distinguishes true unsupervised task completion from remote monitoring or teleoperation.
Supervisory control	Human oversight in which the person assigns objectives, monitors status, manages exceptions, and intervenes when authorized or required rather than continuously controlling machine motion.	Helps distinguish fleet oversight from direct remote operation.
Operator intervention	A human action that changes, pauses, overrides, or terminates automated or autonomous operation.	Creates a consistent event category for safety learning and utilization analysis.

Operational Autonomy

These terms describe the shift from individual automated functions toward completion of larger tasks and coordinated work:

Term	Intended scope	Why it matters now
Task automation	Automation applied to a defined portion of work rather than the complete mission or operation.	Establishes a measurable unit below complete operational autonomy.
Operational autonomy	Capability to complete a meaningful portion of a job within defined conditions with limited direct human control.	Captures progress beyond individual functions without implying universal or unrestricted autonomy.
Autonomous mission	A defined objective, operating domain, start condition, completion condition, and set of constraints assigned for autonomous execution.	Provides a common unit for planning, performance, and completion measurement.
Fleet autonomy	Coordinated autonomous operation of multiple machines under a shared management or supervision model.	Needed as deployments move from one autonomous machine to many.
Multi-machine autonomy	Autonomous execution in which two or more machines coordinate actions, sequencing, or shared resources to complete related work.	Clarifies coordination without requiring one centrally managed fleet.
System-of-systems autonomy	Coordinated autonomous operation involving independently managed machines, platforms, or services working toward a shared objective.	Addresses farms and jobsites where multiple systems retain independent control and ownership.
Orchestration	Coordination of machines, systems, people, and workflows to sequence work and achieve a shared operational objective.	Describes the management layer that connects individual autonomous capabilities into useful operations.

Safety and Assurance

These concepts describe expected system behavior when conditions change, capability is lost, or work cannot continue as intended:

Term	Intended scope	Why it matters now
Minimum risk condition	A stable and acceptably safe condition entered when a machine cannot continue the assigned operation as intended.	Provides a consistent endpoint for fallback and incident analysis.
Safe state	A machine or system condition in which the risk associated with continued operation has been reduced to an acceptable level for the circumstances.	Useful across automation levels, while recognizing that stopping is not always the safest response.
Degraded mode	A reduced-capability operating state used when sensing, positioning, connectivity, computation, actuation, or another required capability is impaired.	Supports clear communication about reduced performance and whether work may continue.
Safety envelope	The set of safety-related conditions and limits within which a machine or system is intended to operate without exceeding defined risk criteria.	Helps connect technical limits, task conditions, and protective behavior.
Operational envelope	The full set of conditions and limits within which a machine or capability is designed to perform its intended operation.	Provides a broader performance boundary that can be distinguished from the safety envelope.
Near miss	An event in which injury, damage, or unsafe operation could have occurred but did not because of intervention, system response, or circumstance.	Creates a common category for learning before an incident occurs.

Readiness and Implementation

These concepts can help the industry assess whether machines, implements, organizations, and people are prepared for deployment:

Term	Intended scope	Why it matters now
Autonomy-ready machine	A machine designed with the sensing, computation, actuation, diagnostics, communications, cybersecurity, interface, and safety provisions needed to support defined autonomous capabilities.	Helps separate present capability from architecture designed for future autonomy.
Autonomy-ready implement	An implement designed with the control, status, safety, communications, and interface provisions needed to participate in defined automated or autonomous operations with a compatible machine or system.	Directly addresses tractor-implement and machine-attachment integration in non-road equipment.
Deployment readiness	The degree to which a defined capability, operating site, support model, governance process, and user organization are prepared for intended use.	Creates a multi-factor benchmark beyond technical availability.
Workforce readiness	The degree to which operators, supervisors, technicians, dealers, managers, and responders have the roles, training, competency, and support needed for deployment.	Recognizes that machine capability does not equal operational readiness.

Interoperability and Coordination

These concepts become critical as mixed fleets, implements, software, and work-management systems must coordinate:

Term	Intended scope	Why it matters now
Mixed-fleet interoperability	Ability of machines, implements, devices, and software from different providers to exchange the information, status, intent, and safety signals needed for coordinated operation.	Addresses a defining reality of agriculture and construction fleets.
Machine-to-machine coordination	Exchange and use of task, position, status, priority, and safety information so machines can coordinate related actions.	Supports safe sequencing, shared work, and collision-risk management.
Machine intent sharing	Communication of a machine's planned action, path, task state, or expected movement to authorized machines, systems, or people.	May provide a foundation for coordination and shared situational awareness.
Autonomous system interoperability	Ability of autonomous machines and supporting systems to exchange and use the information and commands required to perform coordinated work while preserving defined authority and safety boundaries.	Extends data exchange into operational coordination and control.

From Definitions to Measurement: Building a Baseline for Industry Progress

Establishing common terminology is a foundational step toward industry alignment, but definitions alone do not show where the industry stands or how it is changing. Once manufacturers, suppliers, customers, regulators, and other stakeholders use consistent language, the industry can begin to establish comparable baselines and identify which applications, operating models, and enabling capabilities are advancing.

The next evolution of the conversation is to leverage these aligned definitions to help benchmark industry baselines, track directional progress, and support education, standards priorities, and policy discussions. This will help the industry better understand key areas such as automated or autonomous operating hours, supervised versus unsupervised use, intervention and near-miss categories, interoperability capability, workforce readiness, deployment readiness, and support infrastructure.

Conclusion

Automation and autonomy will continue to evolve across agriculture, construction, mining, forestry, and other non-road equipment applications, but their successful adoption depends on more than technology alone. The industry must be able to communicate clearly about what a system does, what responsibilities remain with people, where and under what conditions the capability is intended to operate, and how the system responds when it encounters a limitation or exception.

This framework contributes to that shared understanding by distinguishing among three different terminology challenges:

1. It points readers to established terms with recognized source authority.
2. It makes visible the words that carry different meanings across sectors and standards.
3. It offers a current working view of emerging concepts that still need non-road industry definition.

Organizing the paper this way avoids creating unnecessary parallel definitions while focusing member attention on the areas where alignment can create the most value.

The paper should be treated as a living alignment resource rather than a final dictionary. Standards will evolve, practical deployments will create new lessons, and proposed definitions may be refined or replaced. Continued conversations among manufacturers, suppliers, dealers, end users, technology providers, safety experts, standards bodies, and policymakers will be essential to test the terminology against real machines, tasks, and environments.

Ultimately, the goal is not simply to agree on words. It is to create a dependable foundation for product communication, customer education, workforce preparation, safety learning, interoperability, policy engagement, and credible industry benchmarking. By aligning terminology before measuring progress, the non-road equipment industry can build evidence that is more comparable, more understandable, and more useful for guiding responsible innovation.

About the AEM Futures Council

"Without disruption and innovation, progress isn't possible."

The global impact of non-road equipment manufacturing on our communities and our economy is well known. Taking that knowledge and the strong commitment of our 1,000-plus member companies to make a difference in our world, our AEM Futures Council has worked to tackle the disruptive trends poised to shape the industry of tomorrow.

Chaired by Dr. Ray Gallant of Volvo Construction Equipment North America, the AEM Futures Council brings together industry leaders and subject matter experts to identify disruptive trends and help members prepare for future challenges and opportunities.

Supported by AEM's Industry Sector leadership teams, the Council delivers value through thought leadership, strategic initiatives, industry insights, and member engagement opportunities designed to strengthen the industry's long-term success. For more information, visit www.aem.org/futurescouncil

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